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Indian Standard

CODE OF PRACTICE FOR THE USE OF SEMICONDUCTOR JUNCTION DEVICES

PART I APPLICABLE TO ALL DEVICES

(Incorporating Amendment No. 1)

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Price Group 8

Indian Standard

CODE OF PRACTICE FOR THE USE OF SEMICONDUCTOR JUNCTION DEVICES

PART I APPLICABLE TO ALL DEVICES

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Indian Standard

CODE OF PRACTICE FOR THE USE OF SEMICONDUCTOR JUNCTION DEVICES

PART I APPLICABLE TO ALL DEVICES

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 9 September 1969, after the draft finalized by the Semiconductor Devices Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard (Part I) has been prepared with a view to providing guidance to all concerned with the design, construction, use or maintenance of equipment using semiconductor devices so that optimum device performance and life may be secured. The code is intended to be of particular interest to the new entrants to the semiconductor device industry and application.

0.2.1 While this standard (Part I) is applicable to all semiconductor junction devices; codes of practice relating to specific types of devices such as diodes, thyristors, etc, are being covered in other parts of this series.

0.3 Assistance has been derived from the following while preparing this standard:

B.S. CP 1016 : Part I : 1968 The use of semiconductor devices, Part I : General consideration. British Standards Institution.

The use of semiconductor devices. Electronic Valve and Semiconductor Manufacturers' Association, UK.

0.4 This edition 1.1 incorporates Amendment No. 1 (October 1972). Side bar indicates modification of the text as the result of incorporation of the amendment.

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part I) is intended to give guidance to all concerned with the design, construction, use or maintenance of equipment using semiconductor devices so that optimum device performance and life may be secured.

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*Rules for rounding off numerical values (*revised*).

2. TERMINOLOGY, GRAPHICAL SYMBOLS AND LETTER SYMBOLS

2.1 Terminology — For the purpose of this standard, the terms and definitions given in IS : 1885 (Part VII)-1965* shall apply.

2.2 Letter Symbols — Letter symbols specified in IS : 3715-1966† shall apply.

2.3 Graphical Symbols — Graphical symbols specified in IS : 2032 (Part VIII)-1965‡ shall apply.

3. BASIC SEMICONDUCTOR PROPERTIES

3.0 Briefly described below are basic semiconductor properties which are fundamental to the proper application of all semiconductor devices if satisfactory initial performance and life are to be ensured. Their relative importance may vary widely from one case to another. These are given as an aid to understanding the reasons for the various recommendations that follow for their proper applications.

3.1 Semiconductor Materials

3.1.1 *General*

3.1.1.1 Semiconductors are materials which have their resistivities lying between those of metals and insulators. The approximate limits of their resistivities lie between 10^{-3} ohm centimetre and 10^{-7} ohm centimetre.

3.1.1.2 The semiconductor materials may be either in polycrystalline or monocrystalline form. However, the monocrystalline form is generally used in the fabrication of the semiconductor devices because of regularity in production, reliability and efficiency.

3.1.1.3 In a semiconductor crystal, the electrons in the neighbouring atoms are bound to each other mainly by co-valent bonds. The electrons are in a state of random thermal agitation. The energy possessed by some electrons at room temperature due to thermal agitation may be sufficient to enable them to break their co-valent bonds and become free electrons. The deficiency produced by the removal of an electron is considered as a hole. This process is known as thermal generation of electron-hole pairs. The motion of a hole actually involves successive motions of structural electrons in the opposite direction, each such motion destroying the original hole and creating a new one; but for present purpose it is sufficient to regard the hole simply as a mobile positive charge carrier and the electron as negative charge carrier. The average time either carrier exists as a free carrier is known as 'life time'. If a hole and a free electron combine, the electrons will fill the deficiency represented by hole and will cease to exist as a free carrier. This is known as 'recombination'.

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*Electrotechnical vocabulary: Part VII Semiconductor devices.

†Letter symbols for semiconductor devices.

‡Graphical symbols used in electrotechnology: Part VIII Semiconductor devices.

NOTE — For convenience of description, both free electrons and holes are referred to as 'carriers'.

3.1.2 *Intrinsic and Extrinsic Conduction* — There are two kinds of semiconductor materials, intrinsic and extrinsic. In the intrinsic semiconductors, there is supposed to be no impurities present and conductivity is due to nearly equal contributions from free electrons and holes which are present in equal numbers, due to thermal effects only. The electrons contribute somewhat more than half the conductivity because they are about twice as mobile as the holes. In the extrinsic semiconductors, impurities will be present which will, increase the conductivity very much compared to the intrinsic semiconductors (*see also* **3.1.4**).

3.1.3 *N- and P-type Semiconductors* — In 'N-type' semiconductor material, the conductivity is predominantly due to the movement of 'free' electrons, which carry negative charges in the direction opposite to the conventional current. In 'P-type' semiconductor material, conductivity is predominantly due to the movement of 'holes' which carry positive charges in the same direction as the conventional current.

3.1.4 *Doping* — Introduction of even very small proportions of suitable impurity atoms (of the order of 10^{-6} to 10^{-9}) (normally too small to be detected spectroscopically) can make an intrinsic semiconductor material increase the conductivity of the material by many orders of magnitude. This process of adding impurities is called doping. Impurity atoms causing N-type conductivity, that is, donate free electrons to the crystals, are called 'donors' and those causing P-type conductivity, that is, accept electrons from the crystal to produce free holes, are called 'acceptors'. Where impurities of both kinds are present, the conductivity type of the material is controlled by the difference in their effective concentration.

3.1.5 *Minority and Majority Carrier* — In N-type material the electrons are present in greater numbers and are therefore called 'majority' carriers, while the holes present are called 'minority' carriers. In P-type material, on the other hand, the more numerous holes present are 'majority' carriers and the electrons are 'minority' carriers.

3.1.5.1 Inside the bulk of any given semiconductor material in equilibrium at any given temperature the product of the free-electron density and the hole density is a constant. In N-type or P-type material the number of carriers of one kind, greatly exceeds that of the other; the total net charge of the carriers is neutralized by the opposite total charge of the fixed ionized impurity atoms.

3.1.6 *Semiconductor Material* — The most common semiconductor materials being used at present are germanium and silicon which at room temperature have their intrinsic resistivities of 47 ohms-cm and 63 600 ohms-cm respectively. Apart from these materials, compound semiconductor and organic semiconductors are being developed for making semiconductor devices. Typical examples are galium arsenide, indium antimonide, cadmium sulphide, cadmium selenide, etc.

3.2 Modification of Conductivity

3.2.1 The conductivity of any specimen of semiconductor material may be raised by increasing the number of carriers. The increase of conductivity is only temporary. When the cause of the increase ceases, the number of carriers present (and thus also the conductivity) decays towards its original equilibrium value in a manner characteristic of the particular specimen and conditions.

3.2.1.1 Means of increasing the number of carriers fall into two groups:

a) The first group includes means by which the carriers are produced within the semiconductor itself. This may be achieved by:
   1) the effects of electromagnetic radiation (visible or invisible),
   2) the effects of increasing temperature,
   3) the direct effects of high electric field strength (within a poorly conducting semiconductor),
   4) the effects of collisions of existing carriers with the crystal structure when the carriers have attained enough energy from an accelerating electric field, and
   5) some other less commonly used effects.

   In all these cases 'excess' carriers are generated in pairs inside the materials, one hole for each electron and the material as a whole remains substantially neutral electrically. Except in the immediate vicinity of junctions or other boundaries, the net charge densities associated with normal semiconductor operating conditions are very small compared with the total charge densities of opposite signs present in the crystal structure.

b) The second group consists of introducing carriers of a single type at a boundary of the semiconductor region in question–normally at its junction with a metallic contact or with another semiconductor region of opposite conductivity type. In this case substantial neutrality is maintained by a redistribution of the carriers of the opposite type already existing in the material, the necessary charge being supplied eventually from some other point of connection to the region in question.

3.2.2 When excess carriers are introduced, and the source of excess carriers is suddenly removed, the number of carriers present decays back to normal approximately exponentially as pairs of carriers of opposite sign mutually annihilate one another with release of energy (usually to the crystal lattice, though sometimes as radiation). The time-constant of the decay (usually referred to the minority or less-numerous carriers only) is the 'life-time' of the carriers and is very sensitive to the presence of imperfections and impurities (deliberate or otherwise) in the crystal structure.

3.2.3 The conductivity of N-type or P-type semiconductor material may also be locally decreased by the application of an electric field that drives the majority carriers (electrons for N-type, holes for P-type) out of the region near the surface or interface (junction) at which the field is applied. This forms a 'depletion layer' of material almost free from carriers; this layer has a high resistivity like that of intrinsic material. The space-charge associated with the field is provided by the fixed ionized impurity atoms, whose charges are normally neutralized by those of the carriers now expelled.

3.3 Semiconductor Junctions

3.3.1 An interface between N-type and P-type regions within a single crystal of semiconductor material is known as a 'junction'. The proportion of deliberately-introduced impurities is normally so small that it does not seriously disturb the regularity of the crystal structure, which is thus continuous across the junction.

3.3.2 Junctions are usually formed by taking semiconductor material of one conductivity type and then introducing an appropriate impurity in sufficient amount to give the material the opposite conductivity type within a defined region. The impurity may be introduced in several ways of which the commonest are 'alloying' and 'diffusion'. In alloying, the prepared crystal is locally melted in contact with the impurity and then allowed to recrystallize. In diffusion, the prepared crystal is not melted, but the impurity is allowed to diffuse into it from the surface for a controlled time at a high temperature. Other methods of junction fabrication like grown junction, grown diffused, alloy diffused, melt-back diffused are also employed.

3.3.2.1 Where a semiconductor device involves several junctions, such as in thyristor, they are sometime made by different processes.

3.3.3 While the fundamental electrical characteristics of all types of junction are similar, certain detailed properties depend on the method of manufacture. Among these are the variation of junction capacitance with voltage (*see* **3.5.1**) and the foward-conduction characteristic at very-low and very-high current densities.

3.4 Basic Junction Static Characteristics

3.4.1 A junction between N-type and P-type semiconductor material has an asymmetric voltage *versus* current characteristic. For moderate voltage (V) and current (I) the relation is approximately:

$$I \approx A\,(e^{BV} - 1)$$

the 'constants' A and B depending on temperature and also varying slightly with V. At moderate forward currents:

$$I \approx Ae^{BV}$$

3.4.2 For most devices (but not all) $B \simeq 35$ to 40 at room temperature, so that the current increases by a factor of ten for a voltage rise of about 60 mV. For a given current, $\mathrm{d}V/\mathrm{d}T \simeq -(2$ to $2.5)$ mV degC in this region. At higher forward currents the effect of unavoidable series resistance modifies the characteristic; additionally, the value of that part of this resistance that lies in the bulk of the semiconductor tends to fall with increase of current ('conductivity modulation'), and this further modifies the observed characteristic. In the 'reverse' direction the current 'saturates' at a small fraction of a volt and remains substantially constant up to the voltage at which carrier multiplication mechanisms become significant usually at or near the breakdown voltage of the junction. The saturation current is an approximately exponential function of temperature, usually doubling for a temperature rise of 8°C to 12°C. At and below room temperature and particularly with the silicon devices where the junction saturation current is low, the behaviour is often complicated in practice by leakage currents, whose dependence on voltage and temperature may be different from that of the saturation current. These leakage currents are often associated with the surface of the device, and may vary considerably.

3.4.3 Although the values of the constants in the above relations can be predicted, the values deduced from simple theory are not always realized in practice, because simple theory ignores many significant details, some of which are very dependent on device structure. The figures given represent good generalizations of current practical values but the device manufacturer's information should be used wherever possible in critical work.

3.4.4 The numerical values of the static characteristics of a junction depend markedly on the semiconductor material used. For example, the forward voltage of a germanium junction at normally used current densities is in the region of 0.25 volts whereas that of a silicon junction is in the region of 0.7 volts. The total reverse current of a silicon junction is approximately one-thousandth of that of a germanium junction.

3.5 Junction Capacitance — Any junction of a semiconductor device has inherent capacitance in addition to that of its connections. There are two types of capacitances encountered in junction devices:

a) Transition (depletion layer) capacitance, and

b) Diffusion capacitance.

3.5.1 *Transition (Depletion Layer) Capacitance* — The junction region in a semiconductor device possesses a strong density of ionized charges and in most cases is equivalent to a parallel plate capacitance, with a capacitance, which is inversely proportional to the applied voltage, the law being approximately:

$$c = \frac{D}{(V_{\mathrm{R}} + E)^{F}}$$

where D is a constant for a given junction; V_R is the applied reverse bias; E is a constant depending mainly on the material (typically about 0.3 V for a germanium, about 0.7 V for silicon); and F is a constant varying between about 0.33 and about 0.5 or more according to the type of junction.

Junction capacitance is not strongly dependent on temperature within the normal working range.

At any reverse bias in excess of 150 to 200 mV (but well below the breakdown voltage), the losses in the capacitance are low; in the forward-biased state the junction conductance shunts the capacitance.

The values of the constants predicted by simple theory are not always found in practice and the device manufacturer's information should be used whenever possible in critical work.

3.5.2 *Diffusion Capacitance* — For any given forward bias a certain amount of excess carriers are present in the steady state. If the forward bias is changed, the amount of excess carriers also changes to a new steady level. The quantity $\frac{dQ_s}{dV_F}$ is called the diffusion capacitance (Qs being the stored charge and V_F being the forward bias). Diffusion capacitance will appear in transistors also due to the presence of excess carriers in the base region when the transistor is in normal operation.

3.6 Junction Breakdown — Despite its name, it is not normally in itself destructive, except through the heating effect due to the electric power dissipation involved.

3.6.1 *Reverse Breakdown* — The reverse breakdown condition is that of a junction sufficiently reverse-biased to make the reverse current much greater than its low voltage saturation value (*see* Fig. 1). The two types of a reverse breakdown of a junction are described below:

a) *Zener Breakdown* — The electric field in the junction increases with the reverse voltage. At a high value of this field (10^6 volts/cm) valence electrons are torn loose and go into conduction band across the junction. The reverse current then increases rapidly and is no longer limited by the device itself but is circuit limited. This process is called 'zener breakdown' or internal field emission. Zener breakdown generally occurs in a heavily doped junction.

b) *Avalanche Breakdown* — The electric charges that flow through the junction receive an amount of energy which is proportional to the voltage across the junction. Every increase in the reverse voltage corresponds to an increase in the energy which is stored up in the moving charges. As soon as this energy exceeds a certain threshold, the carrier acquires enough energy between collision with lattice atoms so that it ionizes the atoms on impact and causes an electron-hole pair. This process becomes cumulative, the liberated electrons liberating other charges in their turn. This is called 'avalanche breakdown'. In this case also the reverse current is not limited by the device itself but is circuit limited as in the case of zener breakdown.

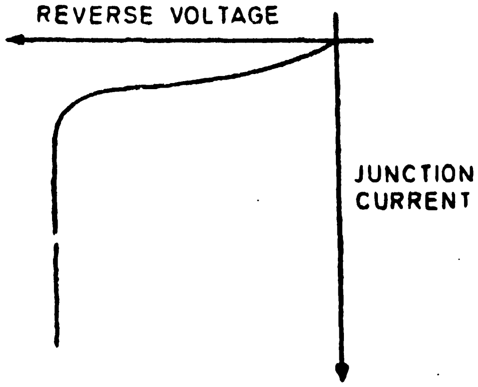

FIG. 1 REVERSE CHARACTERISTIC OF JUNCTION

3.6.2 *Thermal Breakdown* — The thermal breakdown is due to the heating effect caused by excessive electric power dissipation. This dissipation may easily become localized at one or more hot spots. The thermal resistance from hot spot to ambient is much higher than that normally measured from the junction as a whole because of the thermal 'spreading resistance' from the very small hot spot. The small size of the hot spot results in very short time-constant for the temperature rise (microsecond values are often observed). This increases the current which further causes heating effect leading to thermal breakdown.

Thermal breakdown may also be due to the heating effect caused by excessive current due to the avalanche or the zener breakdown.

3.6.3 *Secondary Breakdown* — In transistors operating in the active region, localization of heating effects can additionally result from local thermal feedback from the collector junction to the emitter junction; the time-constants here are usually longer, in the millisecond region. The localization effects are responsible for the phenomenon known as 'secondary breakdown' in which the temperature of the hot spot may be sufficient to damage the device.

3.6.4 If the energy dissipated on any one occasion is small enough, these hot-spot effects are not always immediately fatal to the device. But if repeated they can cause initially unnoticeable cumulative degradation culminating in the catastrophic failure in service. Special care is necessary in switching reactive loads, both capacitive and inductive.

3.6.4.1 Special devices (voltage reference diodes, 'controlled-avalanche' rectifier, etc) exist where design and construction are such as to prevent hot-spot formation within a specified working reverse-current range (often a function of both temperature and time).

3.6.4.2 Only devices specifically intended for operation in the breakdown mode should be so used. Note in particular that breakdown operation of the base-emitter junction of a transistor, although it may not involve any apparent risk of catastrophic failure, may cause gradual changes in the normal characteristics of the transistor. In case of doubt the manufacturer should be consulted.

3.7 Frequency Dependence — The electric charge carriers (holes and electrons) take a finite time to move within the solid material of the device, and consequently certain of its characteristics change noticeably as its operating frequency is increased. The power dissipated within the device due to the carrier storage effect (**3.8**) also rises with frequency. For these reasons the manufacturer may relate certain of his published ratings and characteristics to frequency.

3.8 Charge Storage Effects — The current in, or the voltage across, a semiconductor device does not necessarily reach its final value immediately upon a change of operating conditions. This, apart from other reactive effects, is because it takes a finite time for the minority carriers in the semiconductor material to attain equilibrium. There are two main effects, a 'forward switching transient' when a junction is biased in the forward direction from a condition of reverse bias, and 'minority carrier storage' when a junction is reverse biased after conducting in the forward direction. Although these effects are usually related they are not always of equal practical importance in a given device.

3.8.1 *Forward Switching Transients* — If current is passed through a junction in the forward direction, the injected carriers change the conductivity of the semiconductor material in the vicinity of the junction. This takes a finite time and the initial voltage drop may be greater than the static value. This effect is sometimes called 'conductivity modulation'. The forward switching transient is expressed in terms of the time taken for the forward voltage transient at constant current, under specified circuit conditions, to decay to a specified fraction of its steady value.

3.8.2 *Minority Carrier Storage* — On switching from forward to reverse bias, the minority carriers will be removed from the semiconductor material or will recombine within the material in a time that is dependent, in general, on the nature of the circuit and the properties of the device. Figure 2 gives the reverse recovery waveform of a diode.

3.8.2.1 The minority carrier storage is sometime expressed in terms of the amount of charge that can be recovered from the device and is an inherent characteristic of the device rather than a measure of its

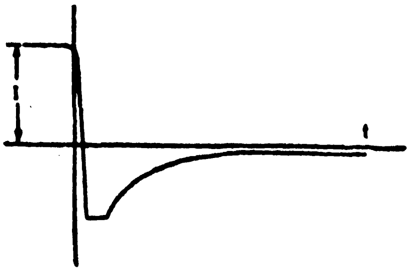

FIG. 2 DIODE REVERSE RECOVERY WAVEFORM

behaviour in a circuit. In some devices the structure is such that the final decay is extremely fast, in the region of a nanosecond (Boff diode). This effect can be used in fast-pulse generators.

3.8.2.2 However, minority carrier storage may also be expressed in terms of the time taken in a specified circuit for the reverse current to fall to a given fraction of the initial forward current. The carrier storage time so expressed will depend on the nature of the circuit as well as the properties of the device.

3.8.3 Stored-charge effects are not normally significant in devices operating in the reverse-breakdown region (such as voltage regulator and voltage reference diodes and avalanche devices), since here the strong local electric field tends. to sweep all carrier away from the active region as soon as they appear. This sweeping action is very much faster than the diffusion processes in the almost field-free region near a forward-biased junction.

4. KINDS OF DEVICES AND MATERIALS

4.1 The semiconductor junction devices which have been developed so far may be divided into following categories:

a) *Diodes*

Examples:

1) Small signal diodes
2) Rectifier diodes
3) Switching diodes
4) Voltage reference and regulator diodes
5) Tunnel diodes
6) Variable capacitance diodes
7) Step recovery diodes
8) Photo diodes

b) *Transistors*

Examples:

1) Low-power small signal transistors
2) Power transistors
3) Switching transistors
4) Field effect transistors
5) Photo transistors

c) *Thyristors*

NOTE — The family of semiconductor devices is increasing and newer developments are continuously taking place in the fabrication of these semiconductor devices. Special mention may be made of integrated circuits in which a number of circuit elements are inseparably associated and electrically interconnected.

4.2 Germanium and silicon are most commonly used material for the fabrication of semiconductor devices (*see* **3.1.6**). The major differences in the devices made with these materials are the following:

a) Silicon can operate at a much higher temperature (at about 200°C) and at much lower value of reverse leakage current. Stable protected junction can be easily formed in the case of silicon devices.
b) Germanium offers lower voltage drop and hence has a higher efficiency in the power rectification on low voltages. Germanium also has an advantage of being used for fabrication of high frequency devices.

5. RATINGS AND CHARACTERISTICS OF SEMICONDUCTOR DEVICES

5.1 General—It is important to distinguish ratings from characteristics. A rating is a limiting condition of usage specified for a semiconductor device by the manufacturer, beyond which the serviceability may be impaired. Characteristics are the measurable properties of a device. For example, maximum collector dissipation, maximum and minimum storage temperatures and maximum reverse voltage are all ratings, whereas leakage current, current gain and mechanical features such as overall length are all characteristics (*see also* **7.5**).

5.1.1 A rating system is a set of principles upon which ratings are established and which determines their interpretation. There are three systems which have been accepted and which allocate responsibility between the device manufacturer and the circuit designer differently. In IS : 3700 (Part I)-1966* absolute maximum ratings have been adopted.

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*Essential rating and characteristics of semiconductor devices: Part I General.

5.1.2 *Spread of Characteristics* — Manufacturers publish the nominal or average values of the characteristics of their devices, but the characteristics of any particular specimen may differ from the nominal. Manufacturer endeavour to keep these spreads as small as possible. It is the practice to quote upper and lower limit values for important characteristics, and in circuit design, allowance shall be made for the spread which will be encountered.

5.1.3 For the purposes of ratings and characteristics, semiconductor devices are divided into three broad groups depending on the cooling conditions and system [reference shall be made to 4 of IS : 3700 (Part I)-1966*].

5.1.4 Ratings and characteristics of different semiconductor devices are covered by the relevant Indian Standards listed in Appendix A.

5.1.4.1 The manufacturer's data sheet specifying the ratings and characteristics of a particular device should be prepared on the lines of the Indian Standards on essential ratings and characteristics, wherever available.

6. PUBLISHED DATA

6.1 When studying a device-manufacturer's published data sheets, the following points should be borne in mind, and in all cases of doubt the device manufacturer should be consulted:

a) The values of limiting ratings and the minimum and maximum values of the major characteristics are pre-assigned and fixed but much of the other information given in the data sheet represents the results of measurements gradually accumulated by the manufacturer over a period of time that may extend to several years. In the early stages of the introduction of a new device, information of this sort shall necessarily be based on a limited number of measurements covering only a short period of production, and so the information in the initial 'provisional' data sheet may not be fully representative of later production devices.

b) The actual publication of a revised version of a data sheet often lags considerably behind the manufacturer's acquisition of the necessary information.

c) The information in a data sheet is usually limited to that which is normally required for the primary intended uses of the device.

d) Where devices bearing the same type-number are made by several manufacturers, various subsidiary characteristics may differ between makes, although the devices all meet the basic specification for the type. Also some manufacturers may claim for their devices a better performance (closer limits, smaller size, or higher limiting ratings) than that required by the basic specification for the type. These differences may be important when considering alternative sources of supply and possible problems of device replacement in the field. However, if the designer avoids reliance on unspecified characteristics, the difficulties will be minimized.

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*Essential rating and characteristics of semiconductor devices: Part I General.

7. ELECTRICAL DESIGN

7.1 Although a 'single' equipment may be built around the actual measured parameters of devices or be based on published typical figures, all commercial designs for batch or mass production shall ensure that:

a) A satisfactory initial yield of good circuits is obtained from the assembly line,

b) Tested circuits will remain within the performance specification for a period of storage (that is, before sale) and during a reasonable working life under any conditions within the general environmental specification for the equipment, and

c) Replacement components can be obtained and fitted to replace any that have failed or have been damaged by abnormal circumstances, so as to restore the performance to specification.

7.2 The design approach is based on either the 'worst-case' or the 'worst-probable-case' philosophy (*see* **7.3** and **7.4**). In either case the effects of tolerances should be examined thoroughly. In practice it is the amount of information and its validity that finally decides the effectiveness of the design. It is rarely possible on economic grounds, for the device manufacturer to give on his data sheet all the desired upper and lower limit values for the user's design analysis but he can normally supply further information on request.

For any design where more than average reliability is required, close co-operation between the designer and the semiconductor device manufacturer is essential.

7.3 'Worst-Case' Design — In the 'worst-case' design every significant parameter for every component, device, supply, input source, output load, control setting, and environment is assigned two limiting values (some of these may be inter-related, for example, resistance values and ambient temperature). The 'tolerance' associated with the nominal value of every characteristic of every component will normally be an 'end of life' tolerance, somewhat wider, than the 'initial selection' tolerance. The equipment is designed so that it will function satisfactorily with any attainable combination whatsoever of the various limiting values, without any absolute limiting ratings being exceeded. For any given part of the circuit it is usually obvious what particular combination of limit conditions impose the most stringent requirements, but where this is not so it may be necessary to evaluate several combinations of limit conditions.

7.4 Worst-Probable-Case Design

7.4.1 In 'worst-probable-case' design, allowance is made for the fact that it is usually extremely unlikely, statistically, that every significant variable will be simultaneously on the adverse limit. If the statistical probability distribution of each variable between its limits is known or assumed (Gaussian, rectangular, etc), it is possible to calculate the probability of the whole circuit (or any given part of it) giving satisfactory performance. Component tolerance may then be relaxed or circuit design simplified, as compared with a 'worst-case' design, until the probability of satisfactory performance is at the economic optimum level. Care shall be taken to allow for any known significant correlations between variables, for example, there will usually be some degree of correlation between any variables having a significant dependence on ambient temperature. Care shall also be taken to ensure that the distributions assumed are not too optimistic; this is particularly true in the case of semiconductor devices where distributions may vary significantly from batch to batch while remaining within an 'overall' distribution. In all critical cases the manufacturer should be consulted.

7.4.2 Great care shall be taken that no unwarrantable assumptions are made about the nature of the signals with which the equipment has to deal. For example, an amplifier intended to handle only speech signals may occasionally have to handle a continuous tone (such as the 'lining-up' tone of a radio transmitter) which could cause the output stage to overheat; for another example, a digital circuit should not be so designed that certain possible input combinations can overload its power supply to an extent that causes malfunctioning, even if the occurrence of these combinations is very unlikely.

7.4.3 The use of 'worst-probable-case' design usually involves a need for extra care in testing the finished equipment (or its sub-units), as compared with the use of 'worst-case' design. However, it should be noted that there is no hard and fast distinction between the two design methods, the difference being one of degree rather than kind, since component tolerances ensure that only rarely does a device operate just at the point at which its characteristics are specified; limiting characteristic values at neighbouring points (for example, gain at various collector currents) can only be inferred, and variations with time can only be estimated.

7.5 Ratings and Deratings

7.5.1 *Ratings* — The manufacturer cannot guarantee satisfactory performance if the ratings are exceeded, although individual devices may for a time appear to operate satisfactorily under 'over-run' conditions. It is, therefore, essential for reliable operation to observe the limiting ratings of all components and devices. In any case of doubt as to which of several related ratings applies in any particular case, the manufacturer should be consulted.

7.5.1.1 Some device ratings are related principally to ageing effects; exceeding these may not cause immediate failure of the device, but cause degradation to proceed more rapidly than is normally acceptable. Others are related to catastrophic failure effects; if these are exceeded there is a risk of immediate failure of the device. The manufacturer may occasionally permit ratings of the first kind to be increased to some extent when only a short life is required of the device; the second kind obviously cannot be raised at all. It is not possible to generalize as to what ratings are of which kind; the manufacturer shall be consulted in each individual case before any liberties are taken with limiting ratings.

7.5.1.2 Many limiting ratings are associated with a time limit, an averaging time, a repetition rate, a duty cycle, or some combination of these. It is not safe to extrapolate beyond the range covered by the manufacturer's information on such ratings; this is particularly important where the device ratings are based on a particular circuit technique in a particular application.

7.5.1.3 To ensure that peak ratings are not exceeded, even momentarily, the use of wide bandwidth oscilloscopes may be essential in the design and development stage, even for circuits intended only for low-speed operation.

7.5.2 *Deratings* — On the other hand, there are good reasons for restricting the operation of any component or device in high-reliability equipment to points well within the manufacturer's ratings. This is called 'deratings'.

7.5.2.1 One reason for derating is the unknown nature of the conditions of maladjustment or external faults or wrong connections that may be applied to the equipment. Although many of these may be foreseen, such as a short-circuit or open-circuit, it is impossible to foresee every case that could conceivably arise. Consequently it is usual to derate devices somewhat, purely as a concession to ignorance. The more closely the possible fault conditions have been studied, the nearer to unity the 'ignorance factor' can be. Once again it is a question of an economic compromise; but an ignorance factor of 0.8 on voltage, current, and power under anticipated fault conditions may be considered reasonable.

7.5.2.2 Another reason for derating is the fact that some ratings are (as mentioned above) a compromise, somewhat arbitrarily chosen by the device manufacturer, between, on the one hand, an attractive device specification and a short expectation of life, and on the other hand a more modest device specification and a very long expectation of life. In such cases, derating may be expected to prolong the life of the device; but (again, as mentioned above) it is impossible to generalize as to which ratings are of this kind. Obviously there is a limit to the extent to which the expectation of life can be increased by derating, even in favourable cases, because whatever mode of failure may be substantially eliminated by derating, other modes of failure will remain. It is difficult to generalize as to the increased life-expectancy to be obtained by derating, and in any critical case the device manufacturer should be consulted. However, it can be said that in general there is little further advantage in life-expectancy to be gained by derating below about 0.7 of the normal rated voltage and current or 0.5 of the normal rated power (the rated values being those appropriate to the conditions of operation).

7.5.2.3 If, for example, the derating of voltage for (a) variations of breakdown voltage with life (say 0.8); (b) ignorance of fault conditions (say 0.8); and (c) prospective increase in life expectancy (say 0.7) is applied cumulatively, the net reduction factor is in this case 0.45. However, if fault conditions are not expected to persist for an appreciable fraction of the total life of the device, it would be reasonable to regard (b) as covered by (c), and to use an overall factor of 0.56.

7.6 Variations of Characteristics with Temperature

7.6.1 The characteristics of semiconductor devices varied with temperature, and this shall be allowed for in circuit design. Indications of the principal temperature effects on a semiconductor P-junction have already been given. Transistor common emitter current gain increases with temperature. The temperature coefficient is usually in the region of 0.7 to 1.3 percent per degree C. Charge storage effects tend to become more pronounced at higher temperatures in most semiconductor devices.

7.6.2 It is important to note that in most cases the significant temperature is not the ambient temperature or the temperature of the case of the device, but that of the active region inside the device. This may be significantly higher than the other two. It is often referred to as the 'junction temperature'.

7.6.3 If the change in device characteristics caused by a rise of temperature causes an increase of device dissipation, this in turn will cause a further rise of temperature. If this positive thermal feedback is sufficiently strong it can lead to a condition of 'thermal runaway', where the device becomes excessively hot and the circuit becomes inoperative. The thermal feedback depends on the circuit design and on the cooling arrangements for the semi-conductor device, Design should be such that the system is thermally stable up to the maximum *junction* temperature (not ambient or case temperature) that will be encountered. The circuit conditions producing maximum dissipation are not necessarily those giving the greatest risk of instability. It may be necessary to consider the effect of an abrupt change of electrical conditions from those of maximum dissipation to those of maximum instability. Class B audio-frequency amplifiers provide a good example of this. Here the most critical condition is usually that which occurs when a sustained signal corresponding to maximum device dissipation is suddenly removed thus subjecting the transistors to the electrical conditions of the quiescent state while their junction temperature has (momentarily) the high value associated with the maximum-dissipation state.

7.7 Variations of Characteristics with Life

7.7.1 All components and devices 'age' to some extent. The change of electrical characteristics is always the result of some form of physical change, but often (particularly in the case of semiconductor devices) the physical change is practically undetectable except by its effects on the electrical characteristics; such changes are frequently merely slight atomic rearrangements within or on the surface of the crystalline semiconductor material. Ageing in itself, is usually a gradual process, and is normally strongly temperature-dependent. A doubling of ageing rate for 10°C rise of temperature is typical; the rate often increases very sharply above some critical temperature. Ageing is often dependent on applied electrical stress, though frequently this is mainly as a result of the temperature rise due to dissipation. But in some types of devices, voltage itself has a significant effect.

7.7.2 Precise general figures for allowance for ageing are obviously impossible to give; in all critical cases the device manufacturer should be consulted. However, some commonly used allowances in worst-case designs are leakage currents (maximum limit at maximum operational junction temperature) multiplied by 2; transistor common-emitter current gain (minimum limit at minimum operational ambient temperature) multiplied by 0.75 (maximum limit at maximum operational junction temperature) mutiplied by 1.25, breakdown voltage variations may be covered by derating to (maximum rated voltage) multiplied by 0.8.

7.7.3 It should be noted that, unlike thermionic valves (which have a well-known 'wear-out' mechanism), semiconductor devices age in basically the same way as passive components. It is, therefore, normally possible to choose devices that have reliability similar to that of the passive components employed with them. Care should be taken when using devices in circuits or environments for which they were not intended by the manufacturer because of the lack of relevant reliability data.

7.7.4 On top of the slow ageing process is superimposed the effect of catastrophic failures. Where no 'wear-out' or fatigue mechanism is involved, these tend to occur more or less at random for any given device type under any given conditions. They are sometimes preceded by a short period of rapid ageing; if this is detected during a maintenance check the device showing it should be replaced (first making sure that the effect is genuinely in the device in question and is not merely a reflection of some other abnormal condition elsewhere in the equipment). In this respect the most sensitive parameters of semiconductor devices are usually leakage current, current gain (of transistors), and breakdown voltage.

7.8 Series and Parallel Operation

7.8.1 When semiconductor devices are connected in series or in parallel, special precautions may be necessary to ensure that the circuit voltage or current is properly shared between device so as to avoid exceeding their individual ratings. The non-linearities and temperature-dependence of device characteristics shall be taken into account, in addition to the wide basic tolerances often encountered.

7.8.2 Voltage-sharing between devices in series may require the use of parallel resistance and capacitance across each device. In some cases it may be necessary to use unequal values of capacitance so as to compensate for different values of stray capacitance between the various devices and the ends of the series chain.

7.8.3 Current sharing between devices in parallel may require the use of resistance in series with each device. In ac applications balancing transformers or series inductors may sometimes be used instead of resistors.

7.8.4 By increasing the number of devices in parallel, it may become possible to tolerate the unbalance resulting from the omission of equalizing components and this solution may sometimes be more economical.

7.8.5 Some degree of matching of the characteristics of the series or parallel devices is often advisable (*see* **7.9**).

7.8.6 Where, say, n devices are connected in series or parallel, the total effective voltage or current rating will normally be less than n times the rating of a single device, because the voltage or current will never be shared exactly equally between the devices. The equality of the sharing, and therefore the extent of the required derating, will depend partly on the matching of the devices and particularly those of any components introduced to control the sharing.

7.8.7 The device manufacturer normally gives recommendations on how to ensure equitable voltage or current sharing between devices of those types frequently used in series or parallel combinations. In all critical cases his advice should be obtained.

7.8.8 In the case of parallel connection of high-current devices, care shall be taken to allow for the impedances of the connections including in particular the resistances of any bolted joints. For special thermal-precautions in parallel and series operations, reference may be made to **9.6**.

7.8.9 Where thyristors or transistors intended to act as switches are connected in series or parallel, care shall be taken to ensure that they all turn on and off together. Trouble can occur here if for any reason the level of the control signal falls.

7.8.10 It is not normally practicable to control reverse breakdown characteristics sufficiently to permit direct parallel operation in the breakdown mode. This applies both to the normal operating range of voltage-reference diodes and to the transient-overload range of controlled-avalanche rectifiers.

7.8.11 The sharing of current and voltage in power stages at high radio frequencies present many specialized problems. Some of these are related to the possibility of operation under conditions of incorrect adjustment, particularly with respect to the level of input drive.

7.9 Matching

7.9.1 Some degree of matching between pairs, quads, or larger numbers of devices often appears desirable, either for push-pull circuits or for series or parallel connections. The need for matching and the degree of matching required should be kept to the minimum by the use of non-critical circuit designs and by the use of negative feedback where practicable. It should be remembered that even if devices are initially perfectly matched they will not necessarily remain so with changes of temperature and lapse of time. Device requirements should also be taken into account.

7.9.2 Two methods of matching that are commonly used are:

a) pairs of devices are selected and packed together as pairs for use; and

b) the whole of the product is graded into narrow-spread groups and these are separately packed, so that any two devices from the same package will be adequately closely matched.

7.9.3 It is usually grossly uneconomic to ask for matching or grading of more than one characteristic of a device. It is almost always cheeper to re-design the circuit to make it more tolerant. This will also improve its stability with time and temperature changes.

7.10 Interference and Spurious Signal

7.10.1 Although interference should wherever possible be reduced to insignificance at source, it is necessary to provide sufficient screening and filtering within any piece of electronic equipment to enble it to function satisfactorily in the interference conditions of its intended environment. Interference may originate from permanent services (for example, lighting equipment), from other fixed equipment (for example, office machines, generators, power-control equipment, particularly that using flow angle control) or from portable equipment (for example, electric tools). Poor maintenance of equipment may allow it to generate much worse interference than would normally be expected.

7.10.2 Internally-generated spurious signals often cause considerable trouble. These signals may arise from unwanted impedances and couplings in the internal supply and earth lines of the equipment. Earthing problems tend to be more important in equipment using semiconductor devices than in equipment using electronic valves because of the higher currents and lower voltages involved in the former. In some equipment it may be desirable to use separate *quiet* (signal) and *noisy* earth lines. The earth lines should be connected together at one point only.

7.10.3 Care should be taken with the selection and layout of decoupling components. The transient and high frequency impedances of capacitors cannot always be predicted from low frequency behaviour and may vary with life.

7.10.4 The problems of interference and spurious signals in digital systems require extremely careful consideration. The measure of the extent to which a digital system can withstand interference and spurious signals without false operation is usually referred to as 'noise margin' or 'noise immunity'. These are general terms that have been used to describe several related but significantly different measures of the basic property of the system.

7.11 Effects of Overdrive and Underdrive — Both digital and analogue circuits can be adversely affected by overdrive and underdrive.

7.11.1 In digital or static switching circuits the dissipation may be quite low under both 'Off' (High) and 'On' (Low) conditions. A degree of underdrive or the halting of a slowly varying input, may provide a destructive 'half way' condition.

7.11.2 The difficulties with analogue circuits usually arise in tuned amplifiers or in those with driver and/or output transformers. Tuned amplifiers should be examined under all conditions from zero drive to well over normal drive including such degrees of mistuning or load disturbance as are likely during operation or setting up. A condition of excess dissipation or excess peak voltage on a junction may be discovered. Parasitic oscillation may also occur with disastrous results under some condition other than the normal design condition. In the circuits using untuned iron cored driver and/or output transformers, the overdrive condition coupled with load mis-matching can cause catastrophic failures. The leakage inductance of the transformer is usually a critical parameter and the transformer maker's *nominal* figure is subject to wide variations due to material, lamination stacking errors, etc, and may be further increased by saturation caused by the overdrive condition itself or an unbalance of dc between the two halves of a push-pull circuit. The values of peak current and peak voltage involved may approach those of an inductive switching circuit and shall be examined against the semiconductor device maker's absolute limiting ratings.

7.11.3 In multi-stage circuits, care should be taken that the adverse effects of overdrive or underdrive are not propagated from stage to stage. Where this cannot be avoided by design, particular care is necessary during setting-up and adjustment (*see* **7.13**).

7.12 Conditions Not Envisaged by the Device Manufacturer

7.12.1 The manufacturer should be consulted before any device is put into service under conditions widely different from those under which the manufacturer intends it to operate and for which he characterises it on its data sheet. This is particularly important in the case of special purpose devices.

7.12.2 There are two reasons for caution in this respect. The first concerns the limiting ratings of the device; warning has already been given of the dangers of extrapolation and interpolation of these. The other reason is that the characteristics of the device may have a very wide spread under conditions outside the range involved in the intended application; the manufacturer may deliberately relax his control on these 'unnecessary' regions of the device characteristics in order to achieve closer or more economic control in the regions that are important in the application for which the device is intended.

7.13 Design Considerations with Regard to the Setting-Up and Adjustment of Equipment

7.13.1 If damage during setting-up and adjustment is to be avoided, the designer shall consider the requirements of these operations all through the design procedure, and not merely as an after thought. The following are some of the design points that are particularly important in equipment using semiconductor devices:

a) Design should, wherever possible, be such that all semiconductor devices remain within their limiting ratings for all combinations of settings (correct and incorrect) of all adjustments, preset or otherwise. Where this cannot be achieved directly in the basic circuit, suitable protective devices (*see* **12**) should be fitted in supply leads or elsewhere as appropriate.

b) Plug-in units intended for maintenance of continuously running equipment shall be designed so that damaging surges do not occur when a unit is connected. (Note here that the order in which the individual contacts of a plug and socket make contact on insertion or break contact on withdrawal is not normally controlled, and may well vary on different occasions of use.)

c) Wherever possible, the necessary facilities should be designed into the equipment so that all routine setting up and adjustment can be done without the use of temporary test connections. Where these cannot be avoided, proper test access points should be provided, so as to minimize the risk of accidental electrical or mechanical damage when applying test probes or clips.

7.13.2 In all cases, but particularly where incorrect procedure might result in device ratings being exceeded, the provision of clear instructions for correct and safe setting-up and adjustment should be regarded as an essential part of the design work. The instructions should include mention of all the precautions needed to minimize the risk of damage. Some of these are:

a) checking supply voltage and polarity or phase rotation before connecting;

b) connecting (and disconnecting) them various inputs, outputs, controls and supplies in the right sequence;

c) checking that any cooling fan or pump motors are rotating in the correct direction before applying the load;

d) performing all the steps of the setting-up and adjusting sequence in the order given, not altering the order or omitting any steps unless this is specifically permitted by the instructions (this applies especially to RF power amplifiers, and to all forms of high-power equipment); and

e) taking great care when applying or removing temporary test connections (probes or clips), and whenever possible switching off the equipment and allowing stored energy in capacitors and inductors to be dissipated before applying or removing such connections.

8. MECHANICAL CONSIDERATIONS

8.1 Outline Drawings — The nature of the applications and the power ratings of semiconductor devices necessitates a wide variety of encapsulations and outlines. In order to achieve some degree of standardization and to facilitate the interchangeability of similar types made by different manufacturers, the outline drawings are given in various parts of IS : 5000*.

NOTE — A list of outline drawings so far prepared is given in Appendix B. These drawings are drawn in accordance with IS: 5001-1969†.

8.2 Mechanical Data — To reduce to a minimum the risk of causing mechanical damage to semiconductor devices during installation, due account shall be taken of the limiting stresses that may be applied to devices. The necessary information should be given by manufacturers in their data sheet for each device the information being in the form of mechanical data as specified in IS : 3700 (Part I)-1966‡.

8.3 Soldering and Welding — Devices should not be soldered or welded at any point except where so intended by the manufacturer. For thermal considerations regarding soldering and welding, *see* **11**.

8.4 Leads and Seals

8.4.1 The maximum force that may be applied to a lead is related not only to the tensile strength of the lead material but also to the maximum stress that may safely be applied to the seal through which the lead or leads pass. Thus in addition to the possibility of breaking the lead, there is a risk that the seal itself may be deformed. Such deformation may impair the hermetic sealing properties of the seal and the electrical characteristics of the device may thereby be adversely affected although under normal environmental conditions this may not become apparent for some time.

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*Dimensions of semiconductor devices.

†Guide for preparation of drawings of semiconductor devices.

‡Essential ratings and characteristics of semiconductor devices: Part I General.

8.4.2 The manufacturer will normally state the length from the seal, over which bending of the leads is not recommended. Some short, thick leads are not intended to be bent at all and in case of doubt the manufacturers should be consulted. When bending leads, the bending radius should be made as large as possible and should not be less than twice the nominal lead wire diameter. Sharp-edged bending tools should be avoided.

8.4.3 To avoid bending the leads too close to the seal, a mounting pad may be used to increase the effective thickness of a printed wiring board, but care should be taken to avoid creating a trap for moisture or for soldering flux.

8.4.4 Where a device is mounted between two 'fixed' pillars or tags, with the lead wires substantially straight and collinear, damaging forces can be exerted as a result of differential thermal expansion or as a result of warping of the base supporting the pillars. In all such cases at least one lead should be deliberately bent or looped to allow some freedom.

8.4.5 Similar considerations will apply where more than two leads are involved.

8.5 Mounting Conditions

8.5.1 The conditions of mounting will depend upon the type of device. It is important to follow precisely any requirement with respect to mounting that may be specified by the manufacturer, since a departure from his recommendations can take the device outside its ratings, with possible damage to the device.

8.5.2 Due regard should be given to the contact potentials that can develop between different materials, particularly under conditions of high humidity and temperature. These potentials can result in actual corrosion of the metal with time, and may lead to the ultimate failure of the device. The combination of a silver or nickel finished device with an aluminium cooling fin is particularly bad from this point of view. The risk of corrosion under these conditions can be greatly reduced by the correct use of aluminium jointing compound followed by a silicone grease.

8.5.3 As device temperatures shall not exceed the rated safe values, the devices shall not be mounted near parts radiating heat, such as mains transformers, electron tubes, valves, high load resistances, etc.

8.5.4 Information on the design of heat sinks for conduction-cooled devices is given in **9.5** to **9.7**.

8.6 Stud-mounted Devices

8.6.1 For stud-mounted devices the manufacturer will normally quote both minimum and maximum ratings for mounting torque.

8.6.1.1 The minimum torque is governed by thermal considerations. It is imperative that each device is mounted so that sufficient pressure exists between the mounting base and the heat sink to permit satisfactory heat transfer away from the device. If the heat transfer is insufficient, the device may be taken outside its electrical and temperature ratings with consequential permanent damage to the device.

8.6.1.2 The maximum torque is governed by mechanical considerations. If the maximum value is exceeded, the device and/or the heat sink may be deformed thereby leading to impaired heat transfer and possible destruction of the device. In addition excess torque may damage the stud, for example, by stripping the threads.

8.6.1.3 To eliminate the risk of exceeding the maximum specified torque, the use of a torque wrench is recommended. The use of pliers for holding devices or nuts during the tightening operation cannot be too strongly deprecated.

8.6.2 It should be noted that the manufacturer will state the mounting torque under specified conditions, and different values may apply if these specified conditions are varied. Thus, if the mounting torque is specified for dry threads, a different value will apply if the threads are greased.

8.6.3 Tapped heat sinks should be machined to provide a mounting surface perpendicular to the axis of the mounting hole. The thread of the stud should already be undercut to allow the heat transfer surfaces to make good contact, but if this is not so, a chamfer just adequate to achieve this should be provided.

8.6.4 When the stud is passed through a clearance hole, a packing washer may be necessary between the heat sink and the fixing nut. Neither clearance holes nor chamfers should be made larger than strictly necessary or heat flow will be impaired.

8.7 Flat Base Devices

8.7.1 Any restrictions given by the manufacturer with regard to the mounting conditions for these devices should be closely followed. These may, for example, take the form of limiting values of torque for the screws used for mounting the device to the heat sink.

8.7.2 Where insulating bushes and/or washers are used, care should be taken that they are the correct size and are correctly assembled so as to secure the device firmly with good electrical and thermal contact.

8.7.3 With a flat base device secured by screws, a suitable spring washer should be used to retain electrical contact between the screw and the device.

8.8 Shrinkage of Insulating Materials — If a stud mounting device is fixed to a material that is liable to shrink or deform under the pressure exerted by the fixing nut, any tag or connection under the nut will then become loose and may cause an open circuit. To overcome this, the use of two nuts with the tag or connection between the tightened nuts is recommended. Any loosening of the device, on its mounting material will then not cause an open-circuited connection.

8.9 Encapsulation of Assemblies — When assemblies containing semiconductor devices are potted, precautions should be taken to ensure that the devices are not damaged by the stresses caused by shrinkage of the potting compound. The advice of the manufacturers of the devices and of the compound should be sought.

9. THERMAL CONSIDERATIONS

9.1 General

9.1.1 The power dissipated within a semiconductor device cause a rise in the junction temperature. The junction temperature should be limited to a safe value so that the device is not damaged and has a long operating life. Manufacturers' data sheets give maximum power ratings for a range of ambient or coolant or case temperatures, depending upon the application, which ensure that the specified maximum junction temperature is not exceeded.

9.1.2 The temperature of the junction (T_J) is determined by the electrical power (P) dissipated at the junction, the thermal resistance (analogous to electrical resistance) from the junction to its surrounding (R_{thJA}) and the ambient temperature (T_{amb}). These are related by the formula:

$$T_J - T_{amb} = P \, . \, R_{thJA}$$

NOTE — This equation for thermal resistance holds good only for steady state conditions and not for pulsed application.

9.1.3 Thermal resistance of the device depends on its encapsulation, method of mounting, and the type of cooling provided. For safe operation, this junction temperature should not be exceeded beyond the specified maximum limits; the thermal resistance should therefore be kept low by appropriate cooling, mounting, etc.

9.2 Natural Cooled (Ambient Rated) Devices — The electrical ratings and characteristics for these devices [*see* **4.2** and **4.2.1** of IS : 3700 (Part I)-1966*] are specified in terms of the ambient temperature at a specified reference point near the device.

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*Essential ratings and characteristics of semiconductor devices. Part I General.

9.3 Forced Circulation Cooled Devices — The electrical ratings and characteristics for these devices [*see* **4.2** and **4.2.1** of IS : 3700 (Part I)-1966*] are quoted for specified cooling conditions. These conditions are determined by the cooling fluid (for example, air or oil), the temperature of the cooling fluid, the device terminations, the flow of the cooling fluid, the orientation of the device and its support, the dimensions of the connections to the device and the surrounding surface conditions. For each individual device type, the manufacturer will state ambient cooling conditions for which the electrical ratings apply. Some devices may be given ratings for more than one set of ambient conditions. As an example, for a power rectifier stack intended for oil cooling, the manufacturer will specify the orientation of the fins, the type of oil and the oil temperature beneath the stack. The same stack could be given electrical ratings relating to forced-air cooling. In this case, the manufacturer will specify the rate of flow of cooling air at a given pressure and inlet temperature.

9.3.1 *Coolant Failure* — Particularly where forced cooling is used it may be necessary to incorporate some form of protective arrangement to protect the semiconductor device from over-temperature arising from a reduction in flow of heat or rise in temperature of the cooling medium.

9.4 Conduction Cooled (Case Rated) Devices — The electrical ratings for these devices are quoted for a specified temperature of a defined reference point, either on the case of the device or on the surface on which it is mounted.

9.4.1 This type of device is normally mounted on some form of cooling fin (heat sink), and, since it is most important to provide good thermal contact between the device and its heat sink care should be taken to ensure that the mating surface of the heat sink is clean, smooth and free from burrs.

9.5 Precautions in Mounting Devices on Heat Sinks — Some manufacturers recommend that the device mounting base should be smeared with a specified inert compound before mounting, in order to minimize the effects of small air gaps caused by any surface irregularities. High thermal conductivity silicone grease is one example of this type of compound. Alternatively a manufacturer may recommend the insertion of a soft metal washer between the device and the heat sink, again with the object of improving the transfer of heat from the device to the heat sink. Such a washer should never be used more than once, since on compression it will work harden and will not subsequently adopt. the contours of the device and heat sink accurately.

9.6 Special Precautions for Devices Connected in Parallel (or Series)

9.6.1 If devices connected in parallel are not adequately bonded together thermally, a form of current hogging may occur leading to thermal instability. This may result in catastrophic failure. If it does not, the effect may pass unnoticed but reliability will be impaired by the over-heating of individual devices.

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*Essential ratings and characteristics of semiconductor devices: Part I General.

9.6.2 Devices connected in parallel should therefore be thermally bonded by being mounted close together on the same heat sink. Where this is impracticable the cooling requirements shall take into account the maximum possible dissipation of each device under unbalanced conditions.

9.6.3 Under certain conditions a similar effect could occur when devices are connected in series.

9.7 Thermal Effects in Encapsulated Assemblies

9.7.1 Where devices are potted, the thermal resistance may be increased or decreased according to the nature of the potting compound. Because of the difficulty of measuring temperature within an encapsulated assembly, care should be taken at the design stage to avoid hot spots in the vicinity of semiconductor devices.

9.7.2 Care should also be taken to avoid excessive temperature in the interior of the assembly during the potting process since heat is released during the setting of many potting compounds.

9.7.3 Before potting with other components, it shall be ascertained from the manufacturer whether the potting temperatures will be injurious to the devices.

10. ENVIRONMENTAL AND INSTALLATION CONSIDERATIONS

10.1 Effects of Atmosphere

10.1.1 Semiconductor devices are normally designed to be resistant to atmospheric conditions in that under normal operating conditions:

a) their external parts are inherently resistant to fungus growth; and

b) their external materials do not blister, crack, soften or flow.

10.1.2 To achieve this the metals used for leads, cases and studs are of corrosion resistant type, or plated or treated to resist corrosion. The device casing is hermetically sealed against the entry of moisture or impurities from its surroundings.

10.1.3 Where a device has to be used in excessively humid or corrosive atmospheres, consult the manufacturer as to its suitability for the extreme conditions likely to be encountered.

10.1.4 Humidity effects can be accelerated by moisture-traps, that is pockets of air not free to circulate. Moisture-traps can also act as flux trap during soldering operations and can thus lead to severe corrosion and leakage Moisture-traps are particularly likely with devices mounted close to printed wiring boards or with certain types of mounting pads.

10.1.5 Accelerated corrosion can arise in humid atmospheres due to contact potentials between dissimilar metals. As far as possible ensure that devices are not mounted so as to give rise to this possibility. In particular, ensure that any mechanical mounting or cooling clip does not give rise to undue contact potential differences (*see* **8.5**).

10.2 Effects of Visible, Ultra-Violet, and Infra-Red Radiation — The encapsulation of some devices may be insufficiently light-tight to eliminate unwanted photoelectric effects. With metal can devices, the only entry point for light is normally through the glass-to-metal seals, and if the device is likely to be operated in a high light level the device should be mounted so that the glass is covered. The same procedure applies where significant amounts of ultra-violet or infra-red radiations are likely to fall on the device. In case of doubt the manufacturer should be consulted.

10.3 Effects of High-Energy Radiation — Semiconductor devices are liable to degradation of characteristics if used in substantial fields of X-rays, neutrons, or other high-energy radiation. Where it is proposed to use devices in such circumstances, the manufacturer should be consulted, since the resistance to high-energy radiation depends on the structure of device.

10.4 Effects of Vibration and Shock — Semiconductor devices, although generally mechanically rugged, can still be damaged by shock, vibration or acceleration. Serious damage may be caused by dropping a device on a hard surface. They should therefore be so mounted that they will not be subjected to conditions beyond their ratings, and because of the large number of unknown quantities involved, a generous 'ignorance factor' should be allowed.

10.4.1 There are three basic methods of mounting; dependent on both the environment and the device, any one of these may be the most suitable. They are:

a) the body of the device rigidly clamped to the equipment structure,

b) the body of the device resiliently supported, and

c) support by electrical connections only.

10.4.1.1 In all cases, but particularly in (b) and (c), care should be taken that vibration cannot cause fatigue and consequent failure of the electrical connections.

10.4.2 In any case where extreme conditions are expected, the device manufacturer should be consulted.

10.5 Effect of Barometric Pressure — Reduced barometric pressure may necessitate the derating of devices. The internal characteristics of devices are not significantly affected by reduced pressure, but voltage derating may be necessary to avoid flashover or corona discharge and dissipation. Derating may become necessary because of impaired cooling.

10.6 Storage and Transport — In storage or transport, the normal precautions used with small electronic components should always be exercised and, in particular, devices should not be subjected to prolonged heat as for example storing near or on top of radiators. Maximum and minimum storage temperatures arc normally given by the device manufacturer.

11. PRECAUTIONS DURING ASSEMBLY OF EQUIPMENT

11.0 General — If the full intended reliability of equipment using semi-conductor devices is to be achieved in service, it is essential to use correct assembly techniques. The use of incorrect techniques, either carelessly of unwittingly, may result in damage that is not immediately apparent but that shortens the life of the device. Some of the points that merit specific attention are described in **11.1** to **11.7**.

11.1 Leads — Lead wires should not be overstressed, or bent too near the seal (*see also* **8.4**).

11.1.1 It should also be noted that when leads, particularly those above about 0.6 mm diameter, are cut to length using conventional type side cutters or pliers it is possible to induce a considerable shock wave into the device through the lead wire at the instant of cutting. Cases have arisen where this shock wave has been sufficient to crack the glass-to-metal seal. It is recommended that the amount of shock reaching the seal be minimized by careful choice of the method of cutting and tools used.

11.2 Cooling Fins — Fitting device to cooling fins (heat sinks) requires care to ensure adequate thermal contact without excessive stress (*see* **8.6**, **8.7** and **9.4**).

11.3 Soldering

11.3.1 For some types of device a heat shunt should be used during soldering operations. For other types it may be permissible to dispense with the heat shunt, provided that the temperature/time cycle is adequately controlled.

11.3.2 Where a device is soldered into circuit by hand, soldering operation should be completed as quickly as possible. A clean, hot, well-tinned soldering iron and good quality solder of appropriate alloy with a non activated resin core should be used. The device leads should not be cut any shorter than necessary. Even where a heat shunt is not essential, for maximum protection, the lead being soldered should be held with a pair of pliers between point where the heat is applied and the body of the device.

11.3.3 The use of a non-earthed electric soldering iron can cause serious damage. The insulation between heater and bit may allow a significant leakage current to flow when the iron is hot. With some designs of iron, a specific earth connection to the actual metal of the bit itself is advisable since corrosion may affect the reliability of the contact between the bit and the normally-earthed supporting stem. In working with specially-sensitive device it may be desirable to make the earth connection of the soldering iron to the earthed framework of the equipment being assembled, to avoid the ask of possible inter 'earth' transient voltages appearing between iron and equipment.

11.3.4 The soldering iron of the gun type with directly heated bits should not be used. Not only is the voltage between different parts of the bit sufficient to cause damage on accidental contact, but the heavy current may cause damage by induction.

11.3.5 It should be noted that a design that is intended for hand-soldering and is satisfactory for this may not be satisfactory for machine soldering and *vice-versa* and an approved method of soldering for any given assembly should not be changed without due consideration. The factors involved include any direct rating limitations on the temperature/time cycle and any indirect effects of differential thermal expansion (the latter can be particularly severe in devices with more than three leads).

11.3.6 When semiconductor devices are soldered to a printed wiring board by a process involving surface contact with a solder wave or the edge of a wire, thermal conditions are rather more severe than for hand holdering. This is because:

a) all leads of a small device are heated simultaneously,

b) adjacent areas of the board are equally hot so that cooling, and is slow, and

c) radiant heat from the solder pot further delays cooling.

11.3.7 Air blast cooling is generally advantageous. Mounting pads can be used to increase the effective lead length on critical devices and so reduce the amount of heat transferred (*see* **10.1**).

11.3.8 No soldering shall be done when the device is live or in circuit under operating conditions.

11.3.9 Most of the requirements specified in **11.3.2** to **11.3.7** may also Apply to dip soldering but, in particular, the reciprocating mechanism which withdraws the board from the surface of the bath should have a quick return motion to minimize retardation of cooling by radiant heat.

11.3.9.1 If dip soldering for printed circuit is employed, the distance between the surface of the solder bath and the step press of the devices like transistors, shall not be less than 5 mm. Normally a dip of three seconds is sufficient to ensure satisfactory connection provided the solder point has been properly prepared beforehand. The dip shall last maximum of five seconds, assuming a solder bath temperature between 230° to 250°C. Forced air cooling of the entire unit shall bring down its temperature to ambient within about 10 seconds.

11.3.10 Beware of flux residues that may become trapped after soldering particularly with machine soldering where active fluxes are used.

11.3.11 Some semiconductor devices may show increased catastrophic failure rates, perhaps intermittently, if ultrasonic agitation of the solder bath is used. The effect may vary from batch to batch of devices.

11.4 Cleaning — When cleaning semiconductor devices or assemblies containing them, one should be beware of the possible damaging effects of any solvents used. Even where the solvents cause no fundamental damage to a device, they may remove the manufacturer's markings and thus give rise to practical difficulties of type or polarity identification; these may make subsequent maintenance operations difficult. The manufacturer's recommendations should therefore be obtained before solvents are used. This is especially important where devices encapsulated in plastics are used. It may be noted that similar devices from different manufacturers may differ in their behavious towards any given solvent.

11.4.1 The device manufacturer should be consulted before subjecting device to any form of ultrasonic cleaning process.

11.5 Surface Damage — Where corrosion resistance is secured by a surface finish, such as solder, gold plating, or paint, one should be beware of accidental damage to the finish. The use of sharp-edged tools for lead forming can give rise to trouble in this way (*see also* **8.4**).

11.6 Magnetic Fields — Semiconductor devices should not be mounted too near strong magnets, such as transformers or loudspeakers. Magnetic materials may be used in the fabrication of a device and excessive magnetic fields can give rise to mechanical distortion and possible damage. When ac is involved the resultant vibration can give rise to fatigue effects, particularly if mechanical resonance occurs as may happen with internal leads.

11.7 Live Cases — The metal cases of devices which are electrically connected internally to one of the device electrodes should be electrically insulated.

11.7.1 This warning applies to any form of metal ase devices.

12. PRECAUTIONS DURING SETTING-UP, ADJUSTMENT, OPERATION AND MAINTENANCE

12.1 If the intended reliability of equipment using semiconductor device is to be achieved in service, it is essential to take certain precautions during. The setting-up, adjustment, operation, and maintenance of the equipment. The designer's instructions (*see* **7.13**) should be closely followed. Normal food engineering practice should be followed in cases not specifically covered by the designer's instructions. Some of the points that merit specific attention are mentioned in **12.2** to **12.5**.

12.2 Because of the low thermal capacities of semiconductor devices, damage may be caused by overloads of relatively short duration. Care should be taken to ensure that connections and polarities are correct before switching in supplies. The sequence of supply switching may be important.

12.2.1 Neither the devices nor the associated components should be inserted or removed with the power supplies switched on.

12.3 Care is also necessary when making circuit adjustments; for example, an accidental short circuit from the base of a transistor to the power supply or across an emitter resistor may cause sufficient current to flow to damage the transistor. Test probes used in checking circuit conditions should always be insulated. Temporary connections should be secured.

12.4 Protective Devices — Adequate protection against damages of power devices against accidental overload or short circuit shall be provided. In some cases slow response time of a fuse may fail to provide the necessary safeguard, in such events quick acting tripping devices shall be used.

12.4.1 When using relays, a diode may be used in the circuit to prevent transistor getting damaged by the induced voltages.

12.5 Great care shall be taken when checking the insulation of an equipment or of a complete installation to prevent the high voltage from an insulation testing equipment being applied directly (or indirectly by leakage, capacity or inductive coupling) to semiconductor devices in such a way that it may cause damage.

12.5.1 Similar considerations apply to earth continuity testing.

13. PRECAUTIONS DURING TESTING OF DEVICES

13.1 It is extremely easy to damage devices by over-dissipation during tests and great care shall be taken to ensure that this does not occur. In particular, the measurement of breakdown voltage should not be attempted without a full appreciation of the problems involved.

13.2 It is essential to check that any test equipment employed is capable of producing sufficiently accurate results under the measuring conditions required. This particularly applies to 'transistor tests'.

APPENDIX A

(*Clause* 5.1.4)

INDIAN STANDARDS ON ESSENTIAL RATINGS AND CHARACTERISTICS OF SEMICONDUCTOR DEVICES

IS : 3700 (Part I)-1966 Essential ratings and characteristics of semiconductor devices: Part I General

IS : 3700 (Part II)-1967 Essential ratings and characteristics of semiconductor devices: Part II Low power semiconductor signal diodes

IS : 3700 (Part III)-I967 Essential ratings and characteristics of semiconductor devices: Part III Rectifier diodes

IS : 3700 (Part IV)-1968 Essential ratings and characteristics of semiconductor devices: Part IV Low power small signal transistors

IS : 3700 (Part V)-1968 Essential ratings and characteristics of semiconductor devices: Part V Power transistors

IS : 3700 (Part VI)-1968 Essential ratings and characteristics of semiconductor devices: Part VI Switching transistors

*IS : 3790 (Part VII)-1970 Essential ratings and characteristics of semiconductor devices: Part VII Reverse blocking triode thyristors

*IS : 3700 (Part VIII)-1970 Essential ratings and characteristics of semiconductor devices: Part VIII Voltage regulator and voltage reference diodes

APPENDIX B

(*Clause* 8.1)

OUTLINE DRAWINGS ON SEMICONDUCTOR DEVICES

IS : 5000 (OD1 to OD9)-1969 Dimensions of semiconductor devices device outlines (OD1 to OD9)

IS : 5000 (OB1 to OB7)-1969 Dimensions of semiconductor devices base outlines (OB1 to OB7)

IS : 5000 (OC1 to OC5)-1969 Dimensions of semiconductor devices case outlines (OC1 to OC5)

IS : 5001-1969 Guide for the preparation of drawings of semiconductor devices

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BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002.
Telephones: 323 01 31, 323 33 75, 323 94 02

Telegrams: Manaksanstha
(Common to all offices)

Regional Offices:		Telephone
Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	323 76 17 323 38 41
Eastern	: 1/14 C. I. T. Scheme VII M, V. I. P. Road, Kankurgachi KOLKATA 700054	337 84 99, 337 85 61 337 86 26, 337 91 20
Northern	: SCO 335-336, Sector 34-A, CHANDIGARH 160022	60 38 43 60 20 25
Southern	: C. I. T. Campus, IV Cross Road, CHENNAI 600113	235 02 16, 235 04 42 235 15 19, 235 23 15
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